US008184507B1

(12) **United States Patent**
Hirano et al.

(10) **Patent No.: US 8,184,507 B1**
(45) **Date of Patent: May 22, 2012**

(54) SLIDER WITH INTEGRATED THERMALLY-ASSISTED RECORDING (TAR) HEAD AND LONG LASER DIODE WITH OPTICAL BODY FOR DIRECTING LASER RADIATION

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **12/969,307**

(22) Filed: **Dec. 15, 2010**

(51) **Int. Cl.**
G11B 11/00 (2006.01)

(52) **U.S. Cl.** **369/13.33**; 369/112.27

(58) **Field of Classification Search** 369/13.33, 369/13.32, 13.17, 13.24, 13.23, 13.14, 13.03, 369/13.02, 13.12, 112.27, 112.09, 112.14, 369/112.21; 360/59, 313, 245.3, 126, 123.17, 360/125.31, 128, 125.74
See application file for complete search history.

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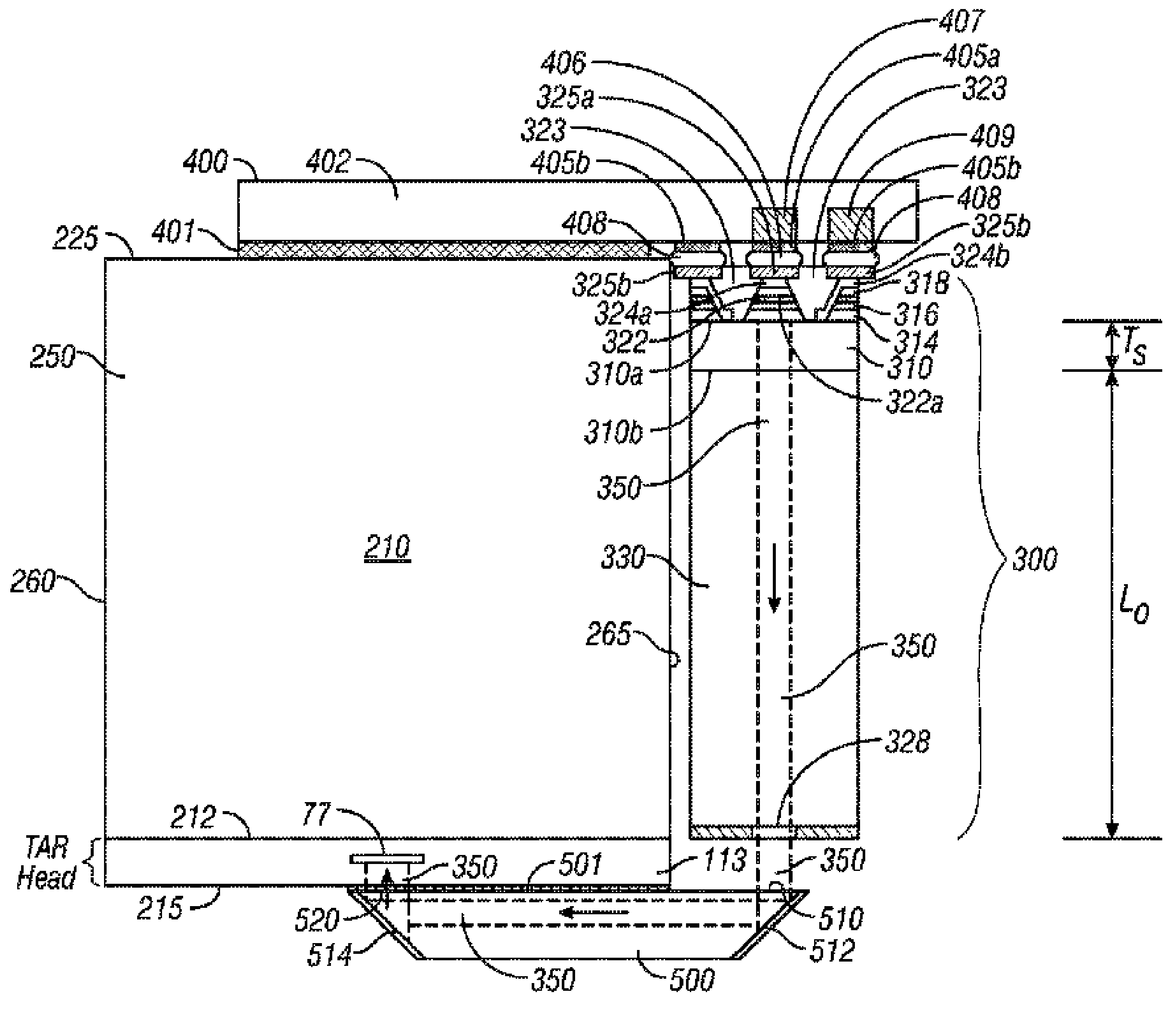
(74) *Attorney, Agent, or Firm* — Thomas R. Berthold

(57) ABSTRACT

A thermally-assisted recording (TAR) slider has an integrated TAR head and an integrated long laser diode, like an external-cavity VCSEL. The TAR head is integrated with the slider at the trailing end and includes an optical waveguide having a grating coupler oriented in a plane generally parallel to the slider trailing end, and a near-field transducer (NFT) at the slider air-bearing surface (ABS) and coupled to the waveguide. A carrier is attached to the slider front end and supports the external-cavity VCSEL so that the linear path of its output laser beam is directed from the slider front end to the slider trailing end. An optical body is attached to the slider trailing end and has an input surface for receipt of the laser radiation from the laser diode, an output surface for directing the laser radiation to the grating coupler, and at least one reflective surface for turning the laser radiation from the input surface to the output surface.

26 Claims, 7 Drawing Sheets



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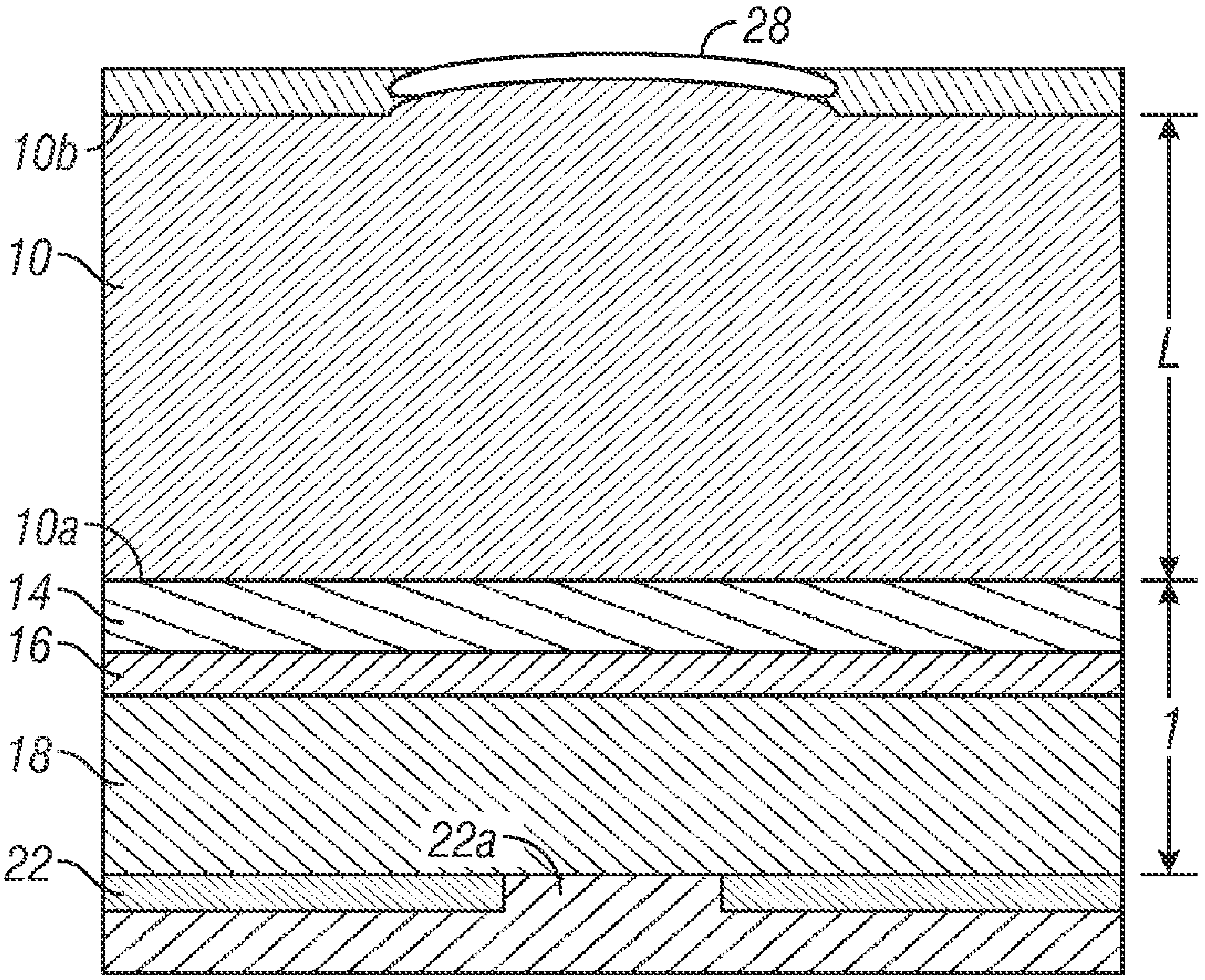


FIG. 1

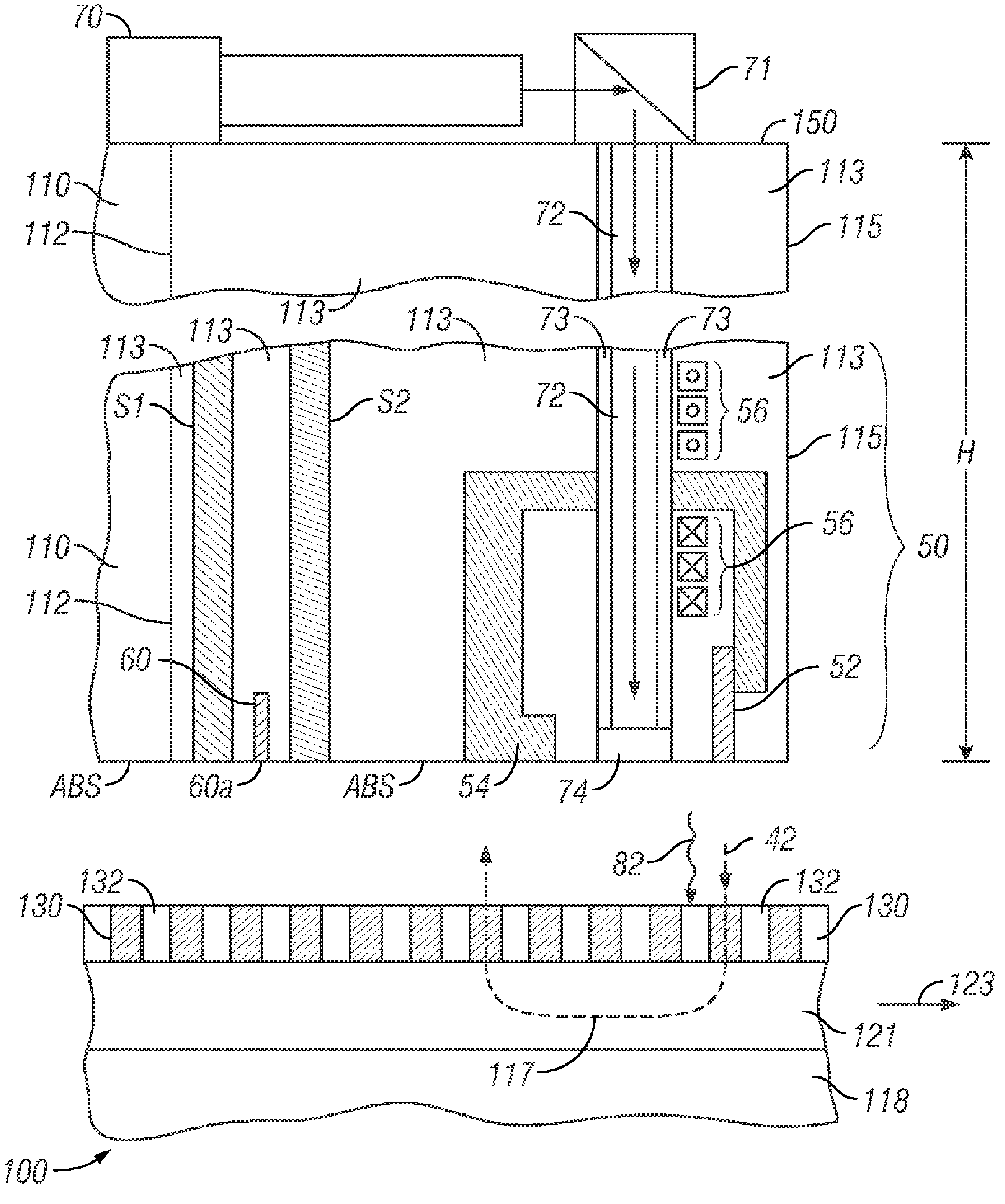
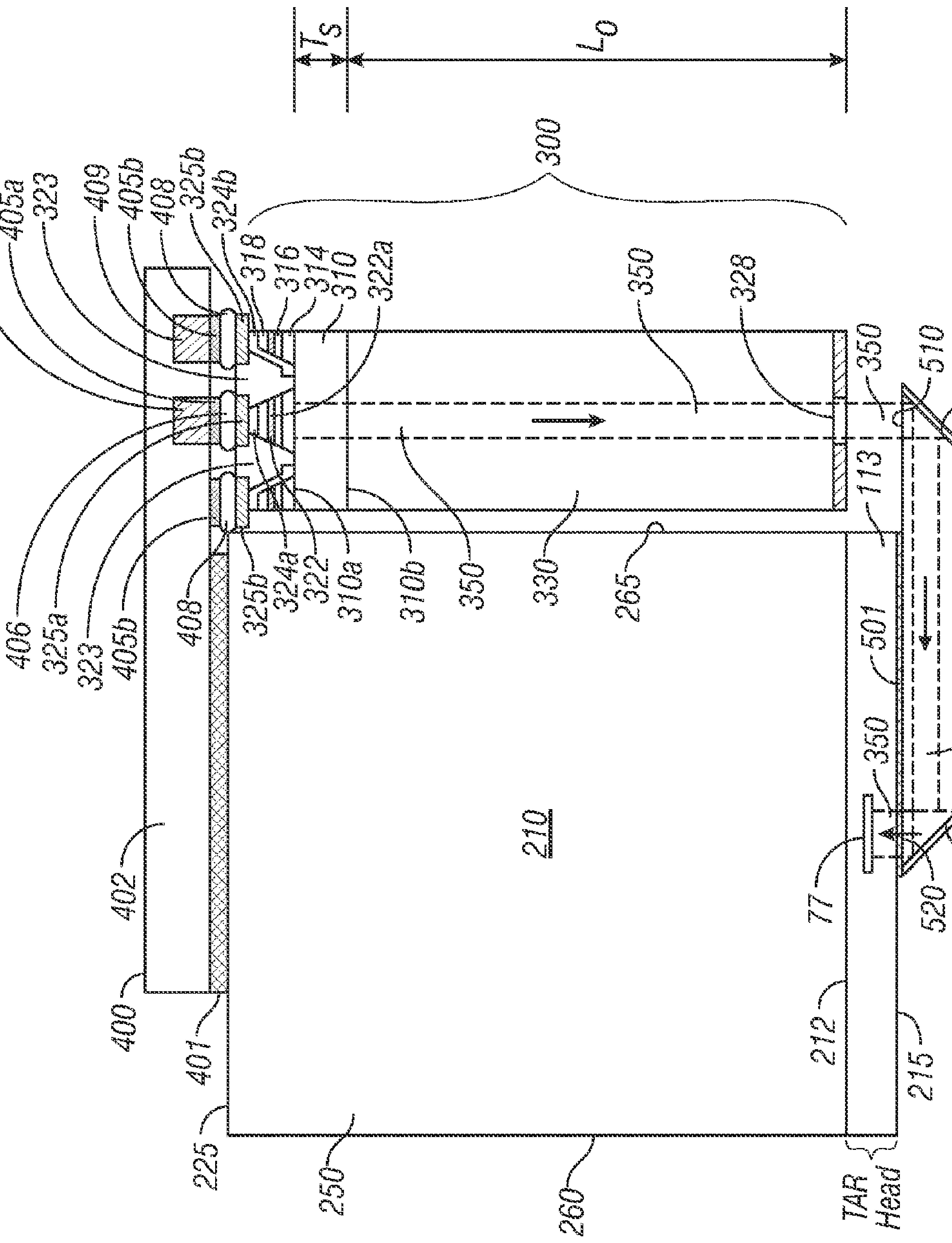


FIG. 2
(Prior Art)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405a
323
409
405b
408
325b
324b
318
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314
310
322a
300
T_S
L_O
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328
350
510
512
406
325a
323
405b
408
325b
324a
322
310a
310b
350
330
265
113
500
501
350
350
402
210
77
520
514
400
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212
215
225
250
260
TAR
Head

FIG. 3

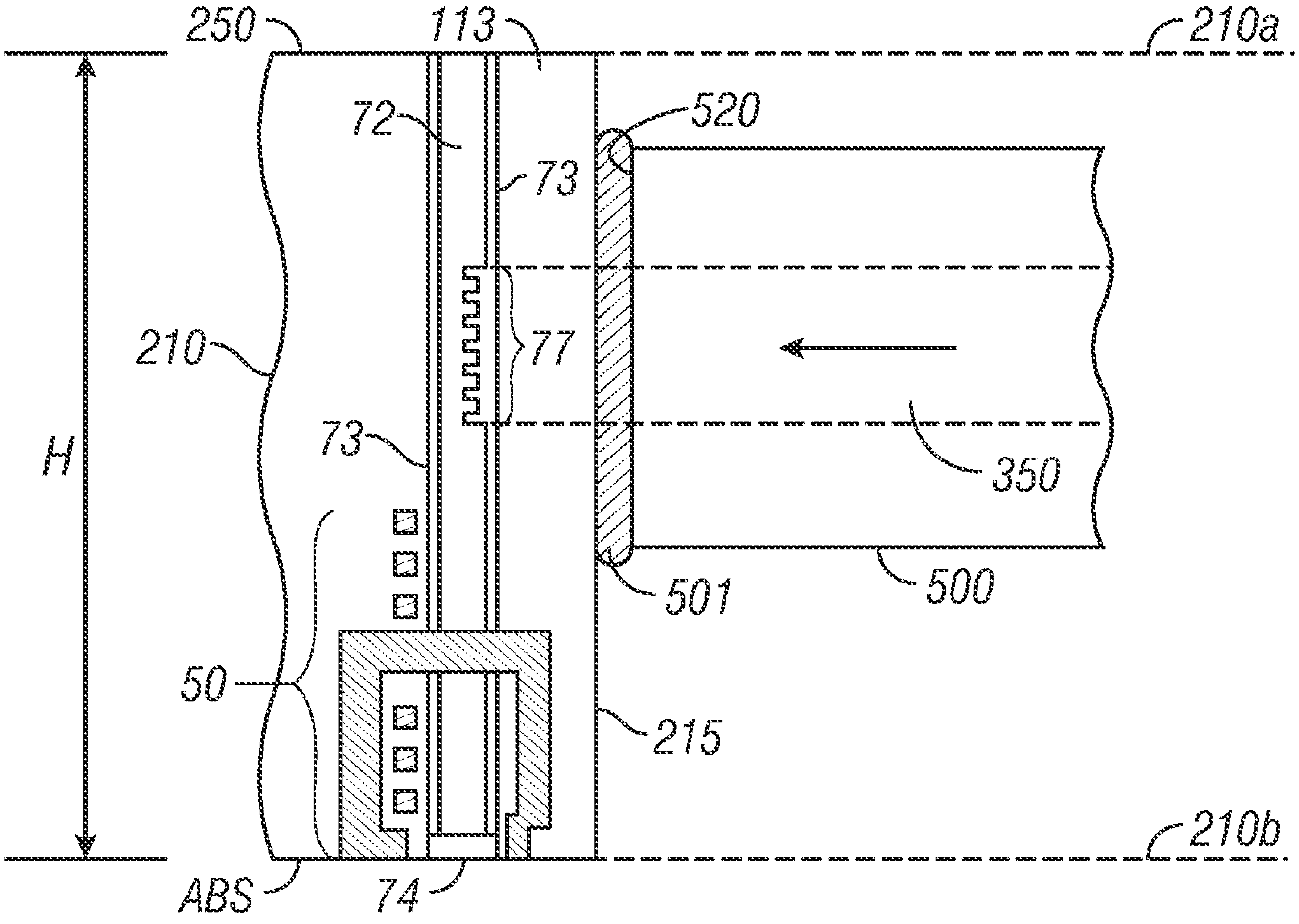

FIG. 4

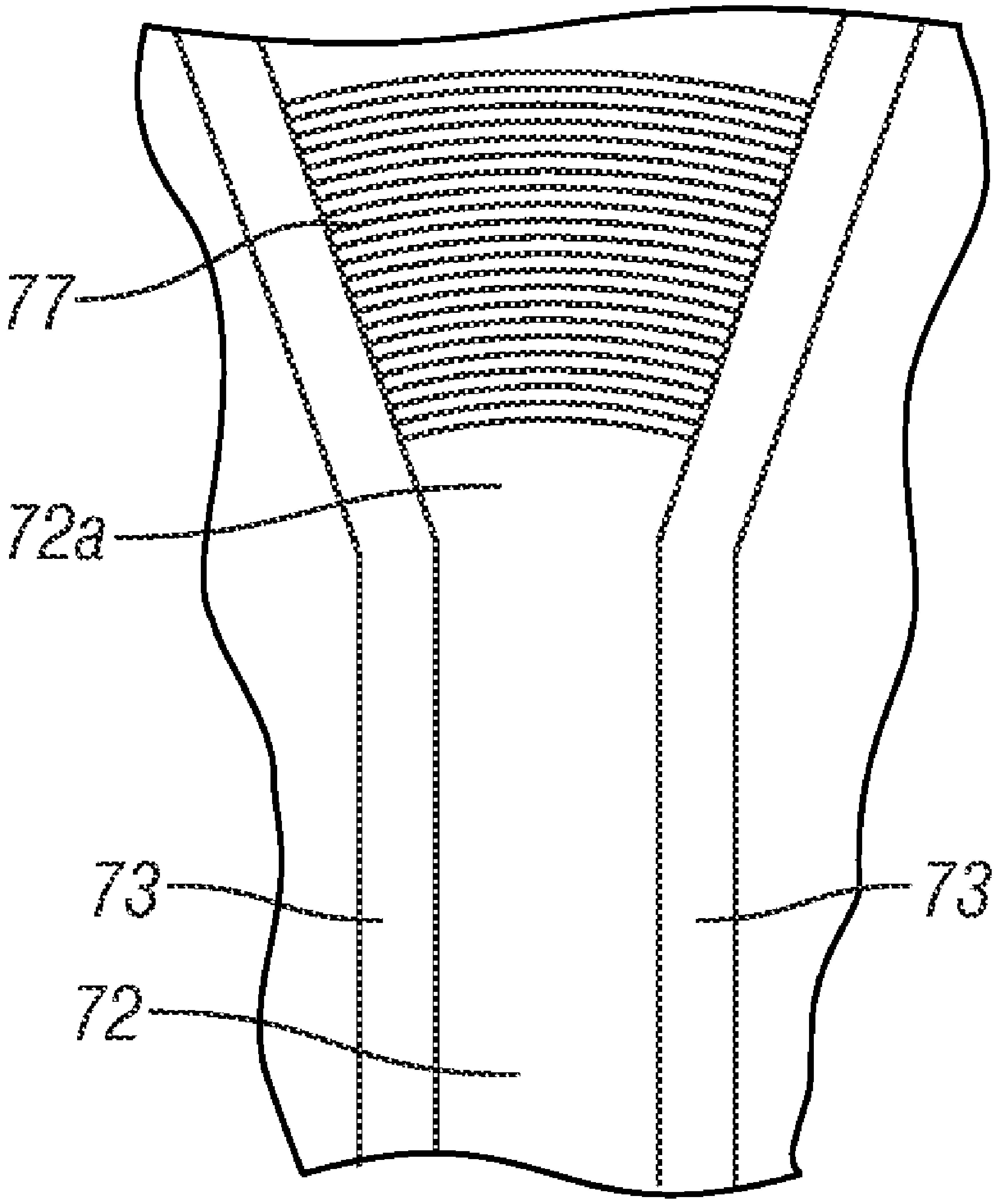

FIG. 5

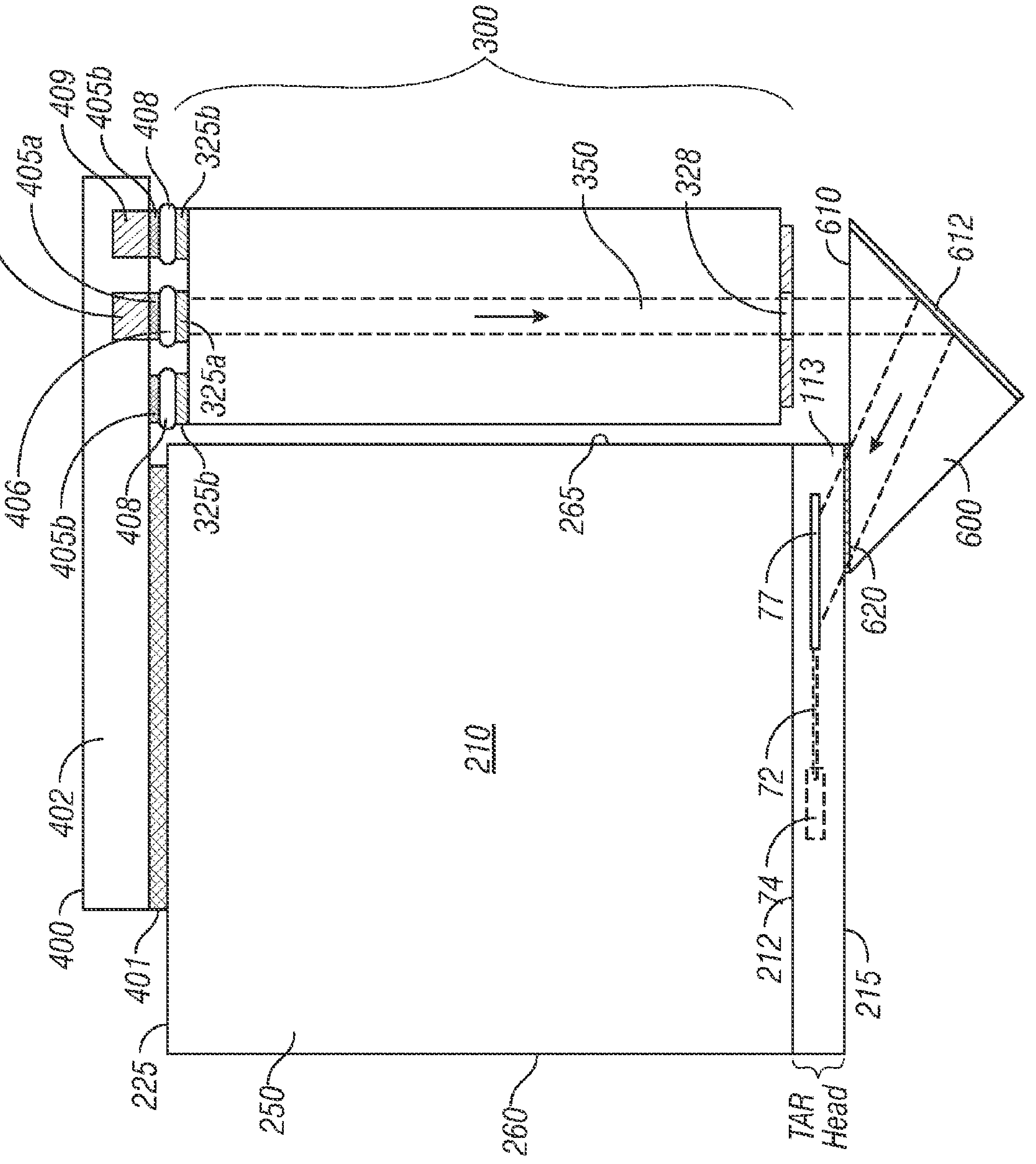
300
409
405b
408
325b
407
405a
350
328
610
612
406
325a
113
405b
408
325b
265
600
620
77
402
210
72
74
212
400
401
215
225
250
260
TAR Head

FIG. 6A

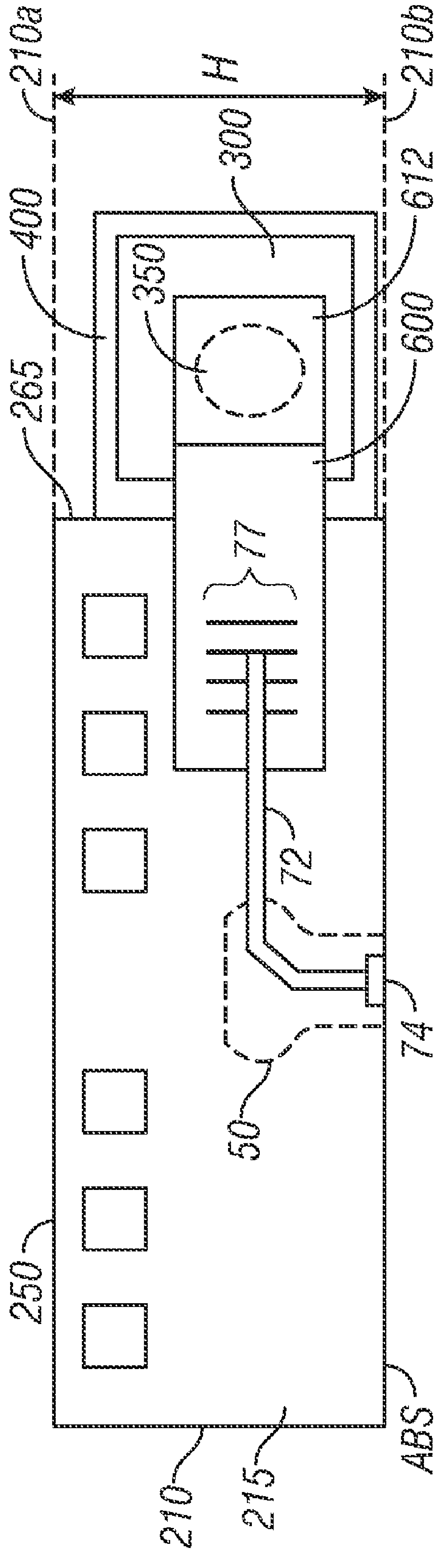

FIG. 6B

SLIDER WITH INTEGRATED THERMALLY-ASSISTED RECORDING (TAR) HEAD AND LONG LASER DIODE WITH OPTICAL BODY FOR DIRECTING LASER RADIATION

TECHNICAL FIELD

This invention relates generally to a thermally-assisted recording (TAR) disk drive, in which data are written while the magnetic recording layer on the disk is at an elevated temperature, and more specifically to a TAR slider with an integrated TAR head and integrated long laser diode, like an external-cavity vertical-cavity surface-emitting laser (VCSEL).

BACKGROUND OF THE INVENTION

Thermally-assisted recording (TAR), also called heat-assisted magnetic recording (HAMR), has been proposed. In a TAR disk drive, an optical waveguide with a near-field transducer (NFT) directs radiation from a laser to heat localized regions of the magnetic recording layer on the disk. The radiation heats the magnetic material locally to near or above its Curie temperature to lower the coercivity enough for writing to occur by the magnetic field from the write head. The recorded data is read back by a conventional magnetoresistive read head. The TAR head, which includes the optical waveguide, write head and read head, is formed on the trailing surface of a head carrier, such as a slider with an air-bearing surface (ABS) that allows the slider to ride on a thin film of air above the surface of the rotating disk. The top surface of the slider (the surface opposite the ABS) is attached to a flexure/suspension assembly so that the slider can be moved across the disk surface by the disk drive actuator. Electrical connections are made from the write head and read head to the disk drive electronics by conductors on the flexure/suspension that connect to electrical contact pads on the trailing surface of the slider.

It is desirable to integrate the laser, which is typically a laser diode, with the slider so that the laser light is directed to the optical waveguide on the slider. This does not present a significant problem for laser diodes, like a vertical-cavity surface-emitting laser (VCSEL), which typically have a relatively short length of about 100 μm, as compared to the slider length of about 850 μm. TAR sliders with various means for attachment of relatively short laser diodes have been proposed. For example, in U.S. 20080002298 A1, the laser diode is formed on a substrate surface that faces the trailing end of the slider, and the substrate is attached by bonding pads that connect the same substrate surface directly to the trailing end of the slider. However, a typical VCSEL has power output of about 10 mW, which is not adequate for currently proposed TAR disk drives, which need a power output of about 50 mW.

Thus more powerful laser diodes, which will typically be longer than VCSELs, are required for TAR. One type of more powerful and longer laser diode is an external-cavity VCSEL, where a third mirror is on the back side of the VCSEL semiconductor substrate. The external cavity and third mirror allow for higher single mode power than can be achieved with a conventional VCSEL. An external-cavity VCSEL is described in U.S. Pat. No. 6,778,582 B1 and by J. G. McInerney, et al., "High brightness 980 nm pump lasers based on the Novalux Extended Cavity Surface-Emitting Laser (NECSEL) concept", *Proc. of SPIE* Vol. 4947 (2003), pp. 240-251. However, because an external-cavity VCSEL has a length of at least at 300 μm and the length of current disk drive sliders is only around 850 μm, there are problems in integrating the laser with the slider with the necessary mechanical support, electrical connections and heat sink requirements. In particular, the trailing end of the slider is not a desirable location because of limited surface area for attachment and because heat from the laser may adversely affect the write and read heads. Also, the top surface of the slider is not a desirable location because the thickness of the slider (the slider "height" between the ABS and the top surface) and its connection to the flexure/suspension assembly cannot be increased without increasing the disk-to-disk spacing in the disk drive, which would undesirably increase the overall size of the disk drive.

What is needed is a TAR slider with an integrated laser diode longer than 300 μm, like an external-cavity VCSEL, that is not attached to the slider top or trailing surfaces.

SUMMARY OF THE INVENTION

The invention relates to a TAR slider with integrated TAR head and an integrated relatively long (greater than 300 μm) laser diode. The laser diode may be an external-cavity VCSEL. The external-cavity VCSEL includes a semiconductor substrate with the VCSEL formed on one surface, an external cavity on the opposite surface, and an output third mirror on the output surface of the external cavity. The external-cavity may be the semiconductor substrate or the semiconductor substrate together with a block of material that is transparent to the laser radiation and is attached to the semiconductor substrate. The TAR head is integrated with the slider at the trailing end and includes an optical waveguide having a grating coupler oriented in a plane generally parallel to the slider trailing end, and a near-field transducer (NFT) at the slider ABS and coupled to the waveguide. A carrier is attached to the slider front end and supports the external-cavity VCSEL so that the linear path of its output laser beam is directed from the slider front end to the slider trailing end. An optical body formed of material, like glass or plastic, that is transparent to the laser radiation is attached to the slider trailing end. The optical body has an input surface for receipt of the laser radiation from the laser diode, an output surface for directing the laser radiation to the grating coupler, and at least one reflective surface for turning the laser radiation from the input surface to the output surface. The grating coupler receives the laser radiation and turns it into the waveguide, which directs the laser radiation to the NFT at the ABS. The height of the carrier, the attached external-cavity VCSEL and the optical body is preferably less than the height of the slider, i.e., the spacing distance between the slider ABS and the slider top surface opposite the ABS.

For a fuller understanding of the nature and advantages of the present invention, reference should be made to the following detailed description taken together with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWING

FIG. **1** is sectional view of a prior art external-cavity vertical cavity surface emitting laser (VCSEL).

FIG. **2** is a sectional view through a portion of a disk and an air-bearing slider that supports a thermally-assisted recording (TAR) head according to the prior art.

FIG. **3** is a top view of a slider with integrated TAR head and integrated external-cavity VCSEL according to one embodiment of the invention wherein the carrier is attached to the front end of the slider and an optical body is attached to the trailing end of the slider.

FIG. **4** is a sectional view along a plane through the length of the slider showing the attachment of the optical body to the slider trailing end and the alignment of the laser radiation beam orthogonal to the slider trailing end for the embodiment of FIG. **3**.

FIG. **5** is a view of the grating coupler and waveguide portion according to the invention as viewed from a direction orthogonal to the slider trailing end.

FIG. **6**A is a top view of a slider with integrated TAR head and integrated external-cavity VCSEL according to another embodiment of the invention wherein the optical body attached to the slider trailing end has only a single reflective surface.

FIG. **6**B is an end view of the slider and attached optical body for the embodiment of FIG. **6**A and illustrates the grating coupler and optical body attachment being near a side of the slider.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** is a sectional view of a monolithic external-cavity VCSEL according to the prior art and as described in U.S. Pat. No. 6,778,582 B1 and in the previously-cited article by J. G. McInerney, et al. The external-cavity VCSEL has a semiconductor substrate **10** with front surface **10***a*, back surface **10***b* and thickness L. A VCSEL with active region **1** is formed on front surface **10***a* and includes gain layer **16** located between partially reflecting intermediate Bragg reflector or mirror **14** and bottom Bragg mirror **18**, and an oxide layer **22** that defines an aperture **22***a*. A partially reflecting output mirror **28** is formed on the back surface **10***b* of semiconductor substrate **10** and functions as a third mirror. The laser radiation is emitted through the third mirror **28**. The semiconductor substrate **10** with thickness L functions as an external cavity for the VCSEL. The external cavity allows for higher single mode power than can be achieved with a typical VCSEL without the external cavity and third mirror. When the external cavity is made from GaAs, the external-cavity VCSEL may be designed to generate laser radiation with a wavelength of greater than approximately 920 nm. For example, the wavelength may be between 920 nm and 1000 nm. Shorter wavelengths require the use of a different substrate due to optical losses in the in GaAs. The external-cavity VCSEL shown in FIG. **1** is a single device that has been cut from a semiconductor wafer onto which the materials making up the various layers have been deposited and patterned using well-known semiconductor lithographic and fabrication processes. Thus a large number of devices are formed on a single wafer. The materials, dimensions and fabrication methods for the external-cavity VCSEL shown in FIG. **1** are described in detail in U.S. Pat. No. 6,778,582 B1.

FIG. **2** is a sectional view through a portion of a TAR disk **100** and air-bearing slider **110** that functions as the head carrier with integrated TAR head, as proposed in the prior art. FIG. **2** is not drawn to scale because of the difficulty in showing the very small features. The TAR disk **100** is depicted as a patterned-media disk with a disk substrate **118** and discrete magnetic islands **130** and nonmagnetic regions **132**. The islands **130** are spaced apart by nonmagnetic regions **132**, which may formed of polymeric material for planarizing disk **100**. The islands **130** are magnetized perpendicularly, resulting in the recorded bits being stored in the recording layer of the islands **130** in a generally perpendicular or out-of-plane orientation. The islands **130** are discrete magnetic islands that function as the patterned bits. A heat sink layer **121** may be located below the islands **130** and nonmagnetic regions **132**. The TAR disk **100** may also be a conventional continuous-media magnetic recording disk wherein the recording layer is not patterned but is a continuous layer.

Also shown on slider **110** with disk-facing surface or air-bearing surface (ABS) is the read head **60** and the write head **50** (with the yoke that connects write pole **52** and a return pole **54**). The ABS of slider **110** is the surface that faces the disk **100** and is shown without the thin protective overcoat typically present in an actual slider. The ABS shall mean the surface of the head carrier that is covered with a thin protective overcoat, the actual outer surface of the head carrier if there is no overcoat, or the outer surface of the overcoat. Write current passes through a coil **56** of the write head **50** to generate a magnetic field (arrow **42**) at the write pole **52**. This magnetic field magnetizes the recording layer on the island **130** beneath the write pole **52** as the disk **100** moves past the write head **50** in the direction of arrow **123**. The detection or reading of the recorded bits is by a read head **60** having a sensing edge **60***a* at the ABS. The read head is typically a magnetoresistive (MR) read head, such as a tunneling MR (TMR) read head in which a sense current passes perpendicularly through the layers making up the head. A pair of magnetic permeable shields S1 and S2 are located on opposite sides of read head **60** to prevent magnetic flux from bits other than the bit being read from reaching the read head **60**. The write coil **56** is shown as a conventional flat or "pancake" coil wrapped around the yoke that connects the write pole **52** with the return pole **54**, with the electrical current directions being shown as into the paper by the coil cross-sections marked with an "X" and out of the paper by the coil cross-sections marked with a solid circle. However, the coil may also be a conventional helical coil wrapped around the portion of the yoke that directly supports the write pole **52**. The slider **110** with integrated TAR head has an outer surface or trailing end **115** with electrically conductive pads (not shown) that connect through the insulating layers **113** to the read head **60** and coil **56** of write head **50**.

The slider **110** also supports a laser **70**, mirror **71**, optical channel or waveguide **72** and near-field transducer (NFT) **74**, which has its output at the ABS. The laser **70** and mirror **71** are shown as being supported on the top surface **150** of slider **110**. The spacing between the generally parallel ABS and top surface **150** defines the height H of the slider **110**, which for conventional sliders is in the range of about 180 to 300 μm. The optical waveguide **72** is depicted in FIG. **2** as extending through the yoke of write head **50** and being located between the write pole **52** and return pole **54**. However the optical waveguide **72** may be located at other locations, such as between shield S2 and return pole **54**, or between the write pole **52** and the outer face of the slider **110**. The waveguide **72** is formed of a core material such as Ta_2O_5 or another high index dielectric material that is transmissive to radiation at the wavelength of the laser and is surrounded by a dielectric cladding layer **73** (for example SiO_2 or Al_2O_3) of lower refractive index than the core material. While the slider **110** in FIG. **2** is depicted as supporting mirror **71** for directing the laser radiation from laser **70** into waveguide **72**, it is known to use a grating coupler coupled to the waveguide, as described for example in U.S. 20090310459 A1.

The NFT **74** is located at the output of waveguide **72** at the ABS of the slider **110**. The laser radiation strikes the NFT **74**, creating concentrated near-field radiation to the islands **130** as the disk rotates in the direction **123** past the slider **110**. A "near-field" transducer, as used herein, refers to "near-field optics", wherein the passage of light is to, from, through, or near an element with subwavelength features and the light is coupled to a second element located a subwavelength distance from the first. NFTs typically use a low-loss metal (e.g., Au, Ag, Al or Cu) shaped in such a way to concentrate surface charge motion at a surface feature shaped as a primary apex or tip. Oscillating tip charge creates an intense near-field pattern. Sometimes, the metal structure can create resonant charge motion, called surface plasmons or local plasmons, to further increase intensity. The electromagnetic field of the oscillating tip charge then gives rise to optical output in the near field, which is directed to the data islands on the disk. The NFT **74** has features less than the wavelength of the laser radiation and the spacing between the NFT **74** and the islands is less than the wavelength of the laser radiation.

When write-current is directed through coil **56**, the write pole **52** directs magnetic flux to the data islands **130**. The dashed line **117** with arrows shows the flux return path back to the return pole **54**. The NFT **74** directs near-field radiation, as represented by wavy arrow **82**, to the data islands **130** as the TAR disk **100** moves in the direction **123** relative to the slider **110**. The electric charge oscillations in the NFT **74** heat the data islands **130**. This raises the temperature of the magnetic recording material in a data island to near or above its Curie temperature to thereby lower the coercivity of the material and enable the magnetization of the data island to be switched by the write field from the write pole **52**.

The TAR head elements, i.e., read head **60**, shields S1, S2, return pole **54**, write pole **52**, coil **56** and waveguide **72**, are fabricated on a trailing surface **112** of slider **110** using well-known conventional thin film deposition and patterning techniques. The TAR head is thus integrated with the slider **110**, with resulting trailing end **115**. Insulating material, typically alumina, is deposited at various times during the fabrication process to separate the various TAR head elements and refill recessed areas, as shown by insulating layers **113**. The insulating material generally surrounds the TAR head elements and provides a portion of the ABS. The slider **110** is typically formed of an alumina/titanium-carbide (Al_2O_3/TiC) composite material. The trailing surface **112** is the surface of a wafer onto which a large number of TAR heads are patterned. The wafer is then diced into individual sliders with the length of the sliders (in the direction perpendicular to trailing surface **112**) corresponding generally to the thickness of the wafer. US 20090258186 A1, assigned to the same assignee as this application, describes a wafer-level process for fabricating TAR heads with thin film waveguides and NFTs.

The invention is a slider with integrated TAR head and an integrated relatively long (greater than 300 μm) laser diode. Preferably the laser diode is an external-cavity VCSEL. An embodiment of the invention is shown in the top view of FIG. **3**. The slider **210** with integrated TAR head has a top surface **250**, a front end **225**, a trailing end **215**, and generally parallel sides **260**, **265**. The slider has a typical length between front end **225** and trailing end **215** of about 850 to 1250 μm. The TAR head is depicted as being integrated with the slider **210** and formed between trailing surface **212** and trailing end **215**. The TAR head includes a grating coupler **77**, which is located in a plane generally parallel to trailing end **215** and is thus depicted in edge view. The external-cavity VCSEL **300** is attached to carrier **400** which is attached to the front end **225** of slider **210**. The external-cavity VCSEL **300** is mounted to carrier **400** so that it is located along a side **265** of slider **210** with its laser radiation beam **350** in the direction from the slider front end **225** toward the slider trailing end **215**. A solid optical body **500** of radiation-transparent material is attached to the slider **210** and directs the laser radiation from the external-cavity VCSEL **300** to the grating coupler **77**.

The external-cavity VCSEL **300** includes semiconductor substrate **310** having generally parallel first and second surfaces **310***a*, **310***b*. The semiconductor substrate **310** may be formed of GaAs or AlGaAs. The first surface **310***a* has deposited on it in succession first Bragg mirror **314**, gain layer **316**, dielectric layer **322** with aperture **322***a*, and second Bragg mirror **318**. An annular isolation trench **323** separates second mirror **318** from the semiconductor substrate **310**. A first electrode layer **324***a* provides electrical contact with second mirror **318** and a second electrode layer **324***b* provides electrical contact with semiconductor substrate **310**. The electrodes **324***a*, **324***b* allow electrical current to flow through the aperture **322***a*. The second surface **310***b* of semiconductor substrate **310** has a block of material **330** attached. The material **330** may be glass or another material transparent to the laser radiation, such as plastic, and may be attached to surface **310***b* by a conventional adhesive, such as epoxy glue. The third mirror **328** for the external-cavity VCSEL **300** is formed on the output side of material **330** opposite to the side attached to semiconductor substrate surface **310***b*. As shown in FIG. **3**, the semiconductor substrate **310** has a thickness T_S and the block of material **330** has a length L_0. In the embodiment of FIG. **3**, the semiconductor substrate **310** and the block of attached material **330** together function as the external cavity with a length $L_1=T_S+L_0$. However, the semiconductor substrate **310** may have a thickness of L_0 so that the semiconductor substrate **310** alone functions as the external cavity, in the manner as shown in FIG. **1**. The semiconductor substrate **310** alone or together with material **330** may have a total length L_1 in the range of about 300 to 1500 μm.

The carrier **400** is attached to the front end **225** of slider **210**, preferably by a layer of adhesive **401** like epoxy, and supports the laser diode. The carrier **400** is attached at the first surface **310***a* of the semiconductor substrate **310**. The carrier **400** may be formed of various materials, including silicon, aluminum nitride ceramic, or beryllium oxide, and fabricated by known microfabrication processes or by conventional machining. The carrier **400** has electrically conductive contact pads **405***a*, **405***b* that connect with contact pads **325***a*, **325***b* connected to electrodes **324***a*, **324***b*, respectively, of the external-cavity VCSEL **300**, preferably by reflow solder joints **406**, **408**. The electrically conductive contact pads **405***a*, **405***b* are connected to respective electrically conductive contact pads **407**, **409** on the top surface **402** of carrier **400**. The top surface **250** of the slider **210** is attached to a flexure/suspension assembly (not shown) which has electrical leads that connect to the contact pads **407**, **409** and thus allow for electrical connection with the laser diode power supply. The attachment of the external-cavity VCSEL **300** to carrier **400** by solder reflow joints **406**, **408** provides for heat sinking from the external-cavity VCSEL **300** through the contact pads **405***a*, 405*b* to the carrier **400** and back to the front end **225** of slider **210**. T*his prevents* heating of the write head and read *head*, which are located at the trailing end **225** of *slider* **210**.

An optical body **500** formed of solid material, like any glass or plastic material that is transparent to the laser radiation, is attached to slider **210** and directs the laser radiation from output mirror **328** to the grating coupler **77**. The body **500** is depicted with its input surface input surface **510** being generally parallel to output mirror **328** and thus orthogonal to the laser radiation beam **350**. However, the body input surface **510** may make an angle with the laser beam **350** to prevent refection back into the external-cavity VCSEL **300**. In the embodiment shown in FIG. **3**, the body **500** is attached to the trailing end **215** of slider **210**, preferably by a layer of adhesive **501** like epoxy, and has an output surface **520** generally parallel to the trailing end **215** of slider **210** and two reflective surfaces **512** and **514**. Each reflective surface **512**, **514** may be a collimator mirror of reflective material, like gold or aluminum, patterned on the outer surface of body **500**. Reflective surface **512** turns the radiation from a direction generally parallel to a side **265** of slider **210** to a direction generally parallel to the trailing end **215**, and reflective surface **514** turns the radiation from a direction generally parallel to the trailing end **215** to a direction generally orthogonal to the trailing end **215**. The laser radiation is then directed to output surface **520** and then to grating coupler **77**.

FIG. **4** is a sectional view along a plane through the length of slider **210** showing the attachment of body **500** by a layer of adhesive **501** to the slider trailing end **215** and the alignment of the laser radiation beam orthogonal to the slider trailing end **215**. Dashed lines **210***a*, **210***b* represent extensions of the slider planes corresponding to the slider top surface **250** and bottom surface (ABS), respectively. The carrier **400** (FIG. **3**), the attached external-cavity VCSEL **300** (FIG. **3**), and the body **500** are all located preferably within the region bounded by the two planes **210***a*, **210***b*. However, the attached external-cavity VCSEL **300** and the body **500** may extend slightly above line **210***a* if allowed by the design of the suspension that attaches to the top surface **250** of slider **210**, for example by providing a hole in the suspension to allow for the slight extension. Thus the carrier **400**, attached external-cavity VCSEL **300**, and optical body **500** do not substantially increase the overall height H of the slider, so there is no need to increase the disk-to-disk spacing of the disk drive.

In FIG. **4**, the laser radiation beam **350** output from output surface **520** has a generally linear path that is depicted as being substantially orthogonal to slider trailing end **215**. However, the laser beam **350** does not have to be orthogonal to slider trailing end **215**, but can make a small angle, which may make the design of coupler **77** easier, as described by Van Laere et al., “Compact Focusing Grating Couplers Between Optical Fibers and Silicon-on-Insulator Photonic Wire Waveguides”, Optical Fiber Communication and the National Fiber Optic Engineers Conference on 25-29 March 2007. The laser beam **350** travels through insulating layer **113** to grating coupler **77** that lies in a plane generally parallel to trailing end **215**. The insulating material **113**, typically alumina, is transparent to the laser radiation, which may have a wavelength between about 920 and 1000 nm. The grating coupler **77** turns the incoming laser radiation and directs it into waveguide **72**, which is located between cladding layers **73**. The waveguide **72** directs the laser radiation to NFT **74** at the ABS. FIG. **5** is a view of grating coupler **77** and shows the tapered input end **72***a* of waveguide **72** as viewed from a direction orthogonal to trailing end **215**. The grating coupler **77** is coupled to the tapered end **72***a* of waveguide **72**, which is located between cladding layers **73**. Grating couplers are well-known and have been proposed for use in TAR heads, as described for example in U.S. 20090310459 A1. Focusing grating couplers and grating couplers coupled to tapered waveguides are described by Van Laere, et al., “Compact Focusing Grating Couplers for Silicon-on-Insulator Integrated Circuits”, *IEEE PHOTONICS TECHNOLOGY LETTERS*, VOL.19, NO. 23, Dec. 1, 2007, pp. 1919-1921.

FIG. **6**A is a top view of a slider with integrated TAR head and integrated external-cavity VCSEL according to another embodiment of the invention wherein the optical body **600** has input and output surfaces **610**, **620**, respectively, but only a single reflective surface **612**. The external-cavity VCSEL **300** is identical to that shown and described in FIG. **3**, so not all details are illustrated. The reflective surface **612** is located in a plane that makes an angle with the incoming laser radiation beam **350** from output mirror **328** so that it is directed from a direction generally parallel to the side **265** of slider **210** to output surface **620** and then through insulating layer **113** to grating coupler **77**. The radiation beam **350** is depicted as being generally orthogonal to input surface **610**, but input surface **610** may be oriented to be non-orthogonal to radiation beam **350** to prevent refection back to the external cavity VCSEL. The radiation beam **350** enters trailing end **215** at a non-orthogonal angle. The grating coupler **77** is offset from the midline between slider edges **260**, **265**, but the waveguide **72** (shown in dotted lines) to which it is coupled is angled downward toward the midline to NFT **74**, which is located at the midline at the slider ABS. FIG. **6**B is an end view of the slider **210** and attached optical body **600** and illustrates the advantage that the grating coupler **77** and the attachment of optical body **600** are located near a side **265** of the slider **210** away from the write head **50** and read head. FIG. **6**B also illustrates that, like the embodiment of FIG. **3**, the carrier **400**, attached external-cavity VCSEL **300**, and optical body **600** do not increase the overall height H of the slider, so there is no need to increase the disk-to-disk spacing of the disk drive.

While the present invention has been particularly shown and described with reference to the preferred embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the spirit and scope of the invention. Accordingly, the disclosed invention is to be considered merely as illustrative and limited in scope only as specified in the appended claims.

What is claimed is:

1. A thermally-assisted recording (TAR) head structure for a magnetic recording disk drive comprising:

a slider having a disk-facing surface, a top surface opposite to and generally parallel to said disk-facing surface, a front end, a trailing end and two sides, the slider having a height defined generally by the distance between the disk-facing surface and the top surface and a length defined generally by the distance between the front and trailing ends;

a laser diode comprising a semiconductor substrate having first and second generally parallel surfaces defining a length greater than 300 μm, the laser radiation beam being output from said second surface in a linear path orthogonal to said second surface, and contact pads on said first surface;

a carrier connected to the contact pads on said first surface of the semiconductor substrate and attached to the front end of the slider, the carrier and connected laser diode being located substantially within a region bounded by upper and lower surfaces generally parallel with the slider top and disk-facing surfaces, respectively, the laser diode being connected to the slider’s front end and extending along a side of the slider with the laser’s linear radiation beam path being in a direction from the slider front end to the slider trailing end; and

a body of material transparent to the laser radiation and attached to the trailing end of the slider, the body having an input surface for receipt of laser radiation output from the laser diode, an output surface near the slider trailing end, and at least one reflective surface for reflecting the laser radiation from the input surface to the output surface.

2. The head structure of claim **1** further comprising at least two solder joints connecting the contact pads of the laser diode to the carrier.

3. The head structure of claim **1** wherein the carrier has a top surface generally parallel to the slider top surface and further comprising electrical conductor pads on the top surface of the carrier and connected to the contact pads of the laser diode.

4. The head structure of claim **1** further comprising an adhesive connecting the carrier to the front end of the slider.

5. The head structure of claim **1** further comprising an adhesive connecting the body to the trailing end of the slider.

6. The head structure of claim **1** wherein said at least one reflective surface on said body comprises a collimator mirror.

7. The head structure of claim **1** wherein the input surface of the body is generally orthogonal to the linear radiation beam path output from the laser diode.

8. The head structure of claim **7** wherein said at least one reflective surface turns the radiation beam from generally parallel to a side of the slider to generally parallel to the trailing end of the slider, and further comprising a second reflective surface on the body for turning the radiation beam from generally parallel to the trailing end of the slider to generally orthogonal to the trailing end of the slider.

9. The head structure of claim **1** wherein the body has one and only one reflective surface and wherein the laser radiation from the output surface of the body is non-orthogonal to the slider trailing end.

10. The head structure of claim **1** further comprising an optical waveguide on the slider oriented generally parallel to the trailing end of the slider, the waveguide having a grating coupler, and wherein the radiation beam from the output surface of the body is aligned with the grating coupler.

11. The head structure of claim **10** further comprising a near-field transducer (NFT) coupled to the waveguide and located at the disk-facing surface.

12. The head structure of claim **1** wherein the laser diode is an external-cavity vertical cavity surface emitting laser (VCSEL) comprising a VCSEL on said first surface of the semiconductor substrate and having first and second mirrors, a gain layer between the mirrors and a dielectric layer having an aperture therein; and an output third mirror on the second surface of the semiconductor substrate.

13. The head structure of claim **12** wherein the semiconductor substrate is the external cavity for the external-cavity VCSEL.

14. The head structure of claim **12** further comprising an external cavity between the second surface of the semiconductor substrate and the output third mirror.

15. The head structure of claim **12** wherein the external cavity comprises a layer of material transparent to the radiation from the external-cavity VCSEL.

16. The head structure of claim **1** further comprising a write head on the slider and having a write pole at the disk-facing surface, and a magnetoresistive read head on the slider.

17. A thermally-assisted perpendicular magnetic recording disk drive comprising:

a perpendicular magnetic recording disk comprising a disk substrate and a perpendicular magnetic recording layer on the disk substrate; and

the head structure of claim **1**; wherein the slider is maintained near the disk with the spacing between the disk-facing surface and the recording layer being less than the wavelength of the laser radiation from the laser diode.

18. The disk drive of claim **17** wherein the perpendicular magnetic recording layer is patterned into discrete data islands.

19. A thermally-assisted recording (TAR) head structure for a magnetic recording disk drive comprising:

a slider having an air-bearing surface (ABS) for facing the disk, a top surface opposite to and generally parallel to the ABS, a front end, a trailing end and two sides, the slider having a height defined generally by the distance between the ABS and the top surface;

an optical waveguide at the slider trailing end and having a grating coupler oriented in a plane generally parallel to the slider trailing end;

a near-field transducer (NFT) at the ABS and coupled to the waveguide;

an external-cavity vertical cavity surface emitting laser (VCSEL) comprising a semiconductor substrate having first and second generally parallel surfaces; a VCSEL on a first surface of the semiconductor substrate and having first and second mirrors, a gain layer between the mirrors and a dielectric layer having an aperture therein; an output third mirror opposite the semiconductor first surface; and an external cavity between the VCSEL and the output mirror; a first electrode connected to the second mirror; and a second electrode connected to the semiconductor substrate; the external-cavity VCSEL having a generally linear laser radiation beam path from the VCSEL through the semiconductor substrate and the output third mirror;

a carrier attached to the front end of the slider and connecting the external-cavity VCSEL to the slider, the carrier and connected external-cavity VCSEL being located substantially within a region bounded by upper and lower surfaces generally parallel with the slider ABS and top surface, respectively, the external-cavity VCSEL being connected to the slider with the radiation beam being parallel to a side of the slider in a direction from the front end to the trailing end of the slider; and

a body of material transparent to the laser radiation and attached to the trailing end of the slider, the body having an input surface generally orthogonal to the radiation beam from the external-cavity VCSEL's third mirror for receipt of the laser radiation from the third mirror, an output surface near the slider trailing end for directing the laser radiation to the grating coupler, and at least one reflective surface for reflecting the laser radiation from the input surface to the output surface.

20. The head structure of claim **19** wherein the semiconductor substrate is the external cavity for the external-cavity VCSEL and the output mirror is attached to the second surface of the semiconductor substrate.

21. The head structure of claim **19** further comprising material transparent to the laser radiation from the VCSEL and located between the second surface of the semiconductor substrate and the output mirror, wherein the external cavity comprises the semiconductor substrate and said transparent material.

22. The head structure of claim **19** further comprising at least two solder joints connecting the first and second electrodes of the external-cavity VCSEL to the carrier.

23. The head structure of claim **19** wherein the carrier has a top surface generally parallel to the slider top surface and further comprising electrical conductor pads on the top surface of the carrier and connected to the first and second electrodes of the external-cavity VCSEL.

24. The head structure of claim **19** further comprising an adhesive connecting the carrier to the front end of the slider.

25. The head structure of claim **19** further comprising an adhesive connecting the body output surface to the trailing end of the slider.

26. The head structure of claim **19** wherein said at least one reflective surface turns the radiation beam from generally parallel to a side of the slider to generally parallel to the trailing end of the slider, and further comprising a second reflective surface on the body for turning the radiation beam from generally parallel to the trailing end of the slider to generally orthogonal to the body output surface.

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